

DEVELOPMENT OF UNIVERSAL SOFTWARE RADIO PERIPHERAL
AMPLIFIER FOR UNDERWATER ACOUSTIC PLATFORM USING
SOFTWARE DEFINED RADIO

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To everyone who told me not to give up.

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ABSTRACT

First and foremost, the development of a modem using the USRP has applications in oceanographic monitoring and communication. Improved acoustic connecting would allow more efficient transfer of information between Underwater Acoustic (UWA) equipment such as autonomous vehicles, piloted vehicles, and underwater profilers. Therefore it can easily be modified in order to be employed for the testing of different UWA. This project describes the full system of an underwater acoustic modem with underwater wireless connection starting with the most critical component of the system which is the USRP amplifier for the receiver and the transceiver. In this project we focused on the development of the USRP amplifier. This amplifier is expected to enhance the signal of the transceiver to Universal Software Radio Peripheral (USRP) modem and the GNU radio. The platform that we proposed uses the Software Defined Radio (SDR) as the main controller. This is due to its flexibility in modulation and able to support coding. Since this is an initial stage, in this work we only use Gaussian Minimum Shift Keying (GMSK) as the modulation techniques. The performance of the UWA platform had been tested and we found that as the frequency increases the attenuation increased as well but with the USRP amplifier we have managed to decrease it. UWA communication research will benefit greatly from the adaption of the USRP as an underwater acoustic modem. The USRP amplifier amplifies the signal that has send by the transceiver and detected by the receiver will effectively demodulate the signal and analyze the received data in the USRP modem. GNU radio and USRP SDR has been successfully implemented. The results demonstrate that the objectives of this research are archived. It is proved that by implementing GNU radio and USRP SDR in the new generation of underwater acoustic communication technology, and improves the utilization of the underwater communication. We conclude that the proper design of the USRP Amplifier is crucial to obtain high quality performance. This project has successfully developed a USRP amplifier and the underwater acoustic communication testbed with expected results.

ABSTRAK

Pembangunan modem menggunakan Universal Software Radio Peripheral (USRP) mempunyai aplikasi dalam pemantauan Oseanografi dan komunikasi. Peningkatan akustik komunikasi akan membolehkan memindahkan maklumat antara Underwater Acoustic (UWA) peralatan seperti kenderaan autonomi, kenderaan diuji, dan profiler bawah air. Oleh kerana hanya, mudah diubahsuai untuk digunakan bagi ujian UWA yang berbeza. Projek ini menjelaskan sistem lengkap dari sebuah modem akustik didalam air dengan sambungan wayarles bermula dengan komponen yang paling penting iaitu sistem penguat USRP desain litar untuk penerima dan pemancar. Dalam projek ini, kami fokus pada pembangunan penguat USRP. Penguat ini diharapkan dapat meningkatkan isyarat transceiver untuk USRP modem dan radio GNU. Platform yang telah dicadangkan menggunakan Software Defined Radio (SDR) sebagai pengendali utama. Ini adalah disebabkan oleh fleksibiliti dalam modulasi dan mampu menyokong pengekodan. Namun, dalam projek ini kita hanya menggunakan Gaussian Minimum Shift Keying (GMSK) sebagai teknik modulasi. Prestasi platform UWA telah diuji dan didapati bahawa frekuensi meningkat, rosokan juga meningkat tetapi dengan penguat USRP dapat menangani masalah rosokan ini. Kajian komunikasi UWA boleh dimanfaatkan dari adaptasi USRP sebagai modem akustik dalam air. Penguat USRP dapat menguatkan isyarat yang sudah menghantar dengan transceiver dan dikesan oleh penerima secara berkesan dengan demodulasi isyarat dan menganalisis data yang diterima di modem USRP dalam projek ini. GNU radio dan USRP SDR telah berjaya dilaksanakan. Keputusan kajian menunjukkan bahawa tujuan dari objektif telah dicapai. Hal ini membuktikan bahawa dengan menggunakan radio GNU dan USRP SDR pada generasi baru teknologi komunikasi akustik bawah air, tidak hanya akan meningkatkan penggunaan komunikasi bawah laut. Kami menyimpulkan bahawa reka bentuk yang Penguat USRP yang sesuai adalah penting untuk mendapatkan prestasi yang berkualiti tinggi. Projek ini telah berjaya membangunkan Penguat USRP dan testbed komunikasi akustik dalam air dengan hasil yang dijangka.

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LIST OF SYMBOLS

α	-	Attenuation
f	-	Frequency
σ	-	Conductivity
λ	-	Wavelength
$e^{\alpha(f)d}$	-	Absorptive loss for acoustic wave propagation
d	-	Propagation distance
$\alpha(f)$	-	Absorption coefficient of frequency f
$f_1 f_2$	-	Relaxation frequency
$P_1, P_2,$	-	Pressure dependencies
A_1, A_2	-	Constants
SNR	-	Desired signal to noise ratio
SL	-	Source level
TL	-	Transmission loss
NL	-	Noise level
Q	-	Total signal sent in the system
$Z_{fr}(\Omega)$	-	Electrical Impedance
ρ	-	instantaneous departure of the pressure
x	-	Mean position
h	-	Mean at depth
ω	-	Angular frequency
P_0	-	Pressure amplitude
Pfa	-	Low probability of false alarm
Pd	-	Probability of detection
T	-	Time

t	-	Sample time
N	-	Number of samples
$Tmeasure_n$	-	Time Measurement
N_{200}	-	Value of the sample
$Ac(\tau)$	-	Amplitude delay profile
M	-	Effective signal length
$\bar{\tau}$	-	Mean delay
τ_{rms}	-	rms delay spread

LIST OF ABBREVIATIONS

AcTUP	-	AIDS Coalition to Unleash Power
ADC	-	Analog to Digital Converter
B&K	-	Brüel & Kjær
BR	-	Bit Rate
COTS	-	Commercial Of The Shelf
CPM	-	Continuous Phase Modulation
DAC	-	Digital to Analog Converter
DBPSK	-	Differential Binary Phase Shift Keying
DDC	-	Digital Down Converter
DSP	-	Digital Signal Processor
DQPSK	-	Differential Quaternary Phase-Shift Keying
DUC	-	Digital Up Converter
ELF	-	Extremely low frequency
FE	-	Front End
FFT	-	Fast Fourier Transform
FHS	-	Frequency Hop Sequence
FIR	-	Finite Impulse Response
FSK	-	Frequency-shift keying
FRONT	-	Front-Resolving Observational Network with Telemetry
GMSK	-	Gaussian Minimum Shift Keying
GNU	-	"Genuinely Not Unix" Operating System composed of free software
GPS	-	Global Positioning System
GSM	-	Global System for Mobile
GSSSM	-	Global Software System for Mobile communications

GUI	-	Graphical User Interface
IF	-	Intermediate Frequency
IIR	-	Infinite Impulse Response
JTRS	-	Joint Tactical Radio System
LDPC	-	Low-Density Parity-Check
MAC	-	Medium Access Layer
MIMO	-	Multiple-Input, Multiple-Output
MSK	-	Minimum Shift Keying
MW	-	Mega-Watt
NIC	-	Network Interface Card
NS	-	Denotes value
OFDM	-	Orthogonal Frequency-Division Multiplexing
OS	-	Operating System
PC	-	Personal Computer
PR	-	Packet Received
PRR	-	Packet Received Ratio
PSK	-	Phase-Shift Keying
QAM	-	Quadrature Amplitude Modulation
QPSK	-	Quadrature Phase-Shift Keying
RF	-	Radio Frequency
Rx	-	Receiver
SDR	-	Software Defined Radio
SNUSE	-	Sensor Networks for Undersea Seismic Experimentation
SWIG	-	Simplified Wrapper and Interface Generator
TRG	-	Telematic Research Group
Tx	-	Transmitter
USB	-	Universal Serial Bus
USRP	-	Universal Software Radio Peripheral
UWA	-	Underwater acoustic
VCO	-	Voltage-Controlled Oscillator

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CHAPTER 1

INTRODUCTION

1.1 Overview

Underwater Acoustic (UWA) has become widely focused from many engineers and it has surfaced as a powerful technique for aquatic applications, and it has attracted more and more attention from the research community recently. UWA communication is beginning to revolutionize our understanding of the physical world by providing fine resolution sampling of the surrounding environment. The ability to have many small devices streaming real-time data physically distributed near the objects being sensed brings new opportunities to observe and act on the world which could provide significant benefits to mankind. For example, dense wireless sensor communication have been used in agriculture to improve the quality, yield and value of crops, by tracking soil temperatures and informing farmers of fruit maturity and potential damages from freezing temperatures [1]. They have been deployed in sensitive habitats to monitor the causes for mortality in endangered species [2]. UWA communications have also been used to detect structural damages on bridges and other civil structures to inform authorities of needed repair and have been used to monitor the vibration signatures of industrial equipment in fabrication plants to predict mechanical failures [3].

Underwater Acoustic (UWA) a kind of measuring and controlling system consisting of unmanned or autonomous underwater vehicles (UUVs/AUVs) and sensor nodes that have sensing, communication computing and moving capabilities.

UWA, which have the features of distributed space, distributed time and distributed function, is a typical autonomous and intelligent system which can independently accomplish specific tasks depending on the changing environment over a given volume of water.

UWAs are envisioned to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications [1]. Multiple unmanned or autonomous underwater vehicles (UUVs/AUVs), equipped with underwater sensors, will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. To make these applications viable, there is a primary need to enable underwater communications among underwater devices.

Acoustic communications are the typical physical layer technology in underwater systems. Wire communications are difficult to deploy and are unsuitable for moving. In fact, radio waves suffer from such high attenuation, while optical waves are affected by scattering and high precision in pointing the narrow laser beams. Acoustic wireless communications enable the UWA [2]. However, the complexity of underwater environment and Acoustic communications are the challenges to UWA. Hence, UWA have become a hot research topic.

The unique characteristics of the underwater acoustic communication channel, such as limited bandwidth capacity, high propagation delays and low reliability are time-variant, space-variant and frequency-variant[3]. Moreover, the ocean environment is dynamic and complex. Hence, theory analyses and precise simulation is difficult for UWA.

A few experimental implementations of underwater acoustic have been reported in the last few years. The Front-Resolving Observational Network with Telemetry (FRONT) project relies on acoustic telemetry and ranging advances pursued by the US Navy referred to as ‘telesonar’ technology [4]. The Seaweb

network for FRONT Oceanographic Sensors involves teleseismic modems deployed in conjunction with sensors, gateways, and repeaters, to enable sensor-to-shore data delivery and shore-to-sensor remote control. Researchers from different fields gathered at the Monterey Bay Aquarium Research Institute in August 2003 and July 2006 to quantify gains in predictive skills for principal circulation trajectories, i.e., to study upwelling of cold, nutrient-rich water in the Monterey Bay, and to analyze how animals adapt to life in the deep sea. However, experiment research on UWA is elementary and seldom work on developing platform for UWA is reported according our knowledge.

In this project, we design and develop a physical experiment platform for UWA. The experiment platform consists of system control of UWA connection, which can complete point-to-point communication performance tests and end-to-end connection experiments. This platform serves as the testing and evaluating system of UWA, which is convenient, flexible and scalable. Based on this experiment platform, a lot experiments are made and a great deal of data on acoustic communication.

1.2 Problem Statement

Though commercial acoustic modems are available, there are not many to choose from and their proprietary nature makes customization of these products expensive or simply infeasible [13]. Researcher's needs a better option to prototype their algorithms and further develop the field of underwater acoustic communication. In particular, the ability to add functionality to a proprietary system is difficult. For example, as researchers we wish to investigate designs with different parameters such as carrier frequency, bit rate, and packet size. To parameterize, commercial modems do not supply the flexibility and commercial modems do not furnish the flexibility to parameterize [15].

For Underwater Acoustic communication the design of the Modem is very important. There are many research on underwater modem for AUV and UUV but however there modem can not support variable modulation. By using SDR platform

user can add coding and varied the modulation to increase the throughput of the transmission.

Since the characteristics of the underwater acoustic channel cannot be properly modeled with a static configuration, it is important to be able to change the properties of an acoustic modem at run time. Underwater acoustic system has the flexibility of software defined radios (SDR) and the advantages of the network layers of GNU Radio and Linux, ultimately providing an end-to-end network for easy underwater development from the physical to application layer.

This thesis describes the full system of underwater acoustic modem with underwater wireless sensor connected to the most critical component of the system which is the USRP modem, hydrophone, and the USRP amplifier design circuit.

1.3 Research Objectives

The main objective of this research is to develop the circuit amplifier with the USRP platform test bed to enable the communications and prove the data is transfer. As a result, the objectives of the proposed research are:

- Develop and Design amplifier for Acoustic transmitter and receiver.
- Implement the amplifier on the USRP Platform.
- Implement the Underwater Acoustic transceiver system.

1.4 Scope of Work

The scope of this research is including exploring on how to use GNU Radio and USRP to construct the acoustic system communication. These includes: learning the python and C++ language, installing the GNU Radio software on Linux, and learn how to use it as the software that will control the USRP board in order to construct the acoustic system communication test bed. Second is the development of the amplifier circuit of the test bed that can configure its modulation according to the system communication of the channel. Third is integrate the circuit amplifier with the USRP platform test of UWA can be configured to improve the communication between the nodes by sensing the packets are bad or good condition. Next is to implement the acoustic system underwater network to prove the data is transfer. The experiment platform consists of system control of UWA connection, which can complete point-to-point communication performance tests and end-to-end connection experiments. This platform serves as the testing and evaluating system of UWA

1.7 Organization of the Thesis

The rest of the thesis is organized as follows: Chapter 2 provides the relevant background for understanding the selection of using acoustic modems instead of RF modems for underwater communication based on the physics of the underwater environment, and also describes existing commercial and research underwater acoustic modems to illustrate the novelty and applicability of our design. Chapter 3 describes all the initial components experiment of the integration System spritely. Chapter 4 describes the USRP Amplifier design and why we need in our research and finally the integration system test results in the water tank. The final chapter concludes the outcomes of the research and proposes a few ideas for future works.